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The Determinants of the Adoption Lag for Advanced Manufacturing Technologies

by John R. Baldwin and Mohammed Rafiquzzaman

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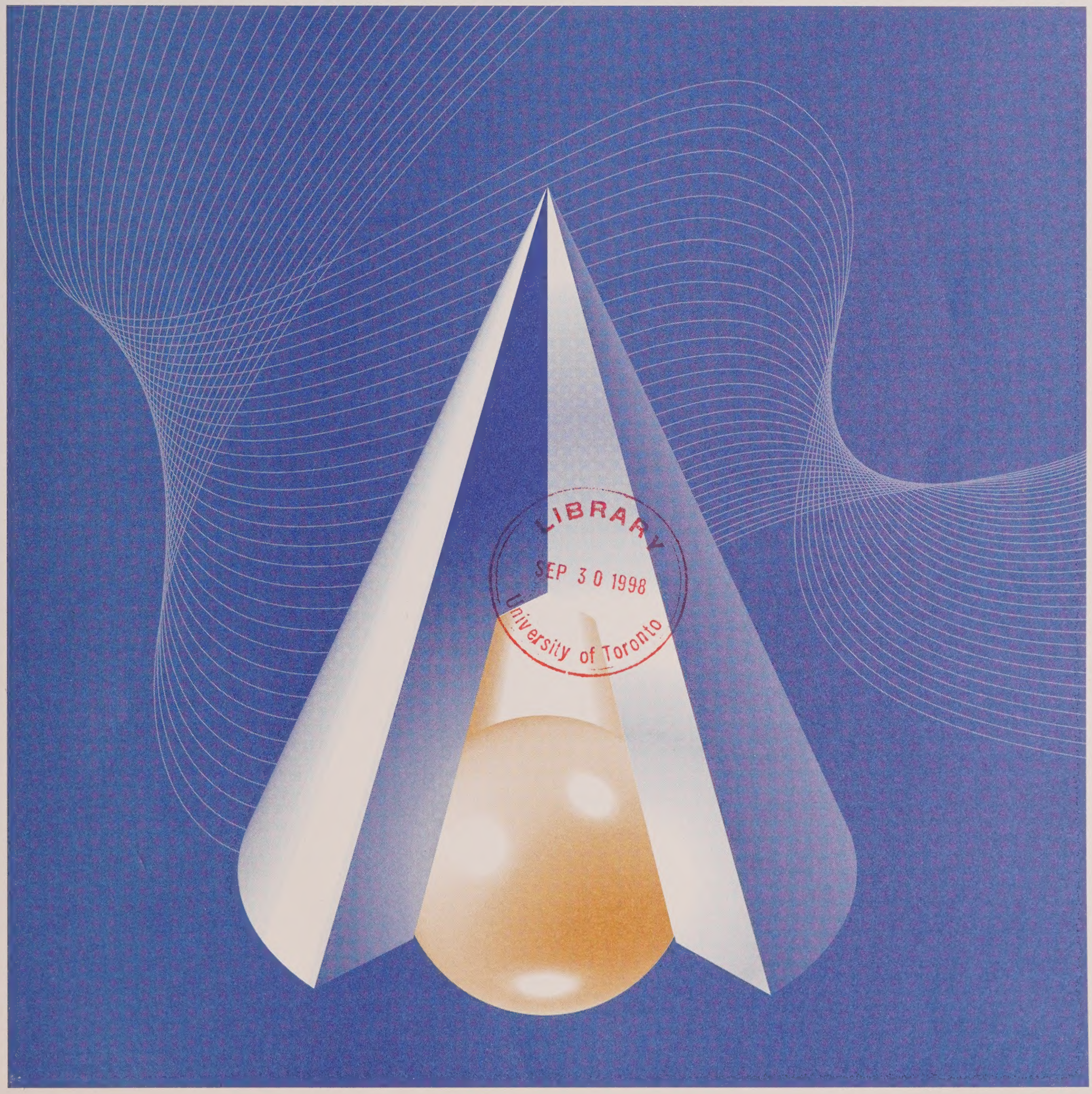

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Abstract

This paper examines the determinants of the adoption lag for advanced technologies in the Canadian manufacturing sector. It uses plant-level data collected on the length of the adoption lag (the time between a firm's first becoming aware of a new technology and its adoption of the technology) to examine the extent to which the adoption lag is a function of the benefits and costs associated with technology adoption as well as certain plant characteristics that are proxies for a plant's receptor capabilities.

Economic theory suggests that the diffusion of advanced technologies should be a function of the benefits associated with the adoption of new technologies. Other studies have had to proxy the benefits with environmental characteristics—like proximity to markets, fertility of soils, size of firm. This paper makes use of more direct evidence collected from the 1993 Survey of Innovation and Advanced Technology concerning firms' own evaluations of the benefits and costs of adoption along with measures of overall technological competency. Both are found to be highly significant determinants of the adoption lag. Geographical nearness of suppliers decreases the adoption lag. Variables that have been previously used to proxy the benefits associated with technology adoption—variables such as larger firm size, younger age, and more diversification by the parent firm also decrease the adoption lag—but they have much less effect than the direct measure of benefits and firm competency.

Keywords: technology, diffusion, adoption lag JEL classification.

1. Introduction

The diffusion of technological innovations, i.e., the process by which the use of new technology spreads, is a key ingredient of technical change and economic growth. Economic growth is a function of technological progress, which depends in turn upon the flow of new technologies and the rate at which these technologies are diffused throughout the economy (Nabseth and Ray, 1974). Because of its importance, the diffusion process has received considerable attention.[1] Different theoretical approaches have been proposed to model the decision by firms to adopt innovations (Davies, 1979, and Stoneman, 1986). Numerous empirical studies have focused on the determinants of diffusion.[2]

Three separate streams of analysis may be identified in the literature dealing with adoption.[3] The first is Mansfield's epidemic model of technology diffusion which remains a basic research tool for both theoretical and empirical analysis.[4] Although Mansfield's model has frequently produced credible empirical results, the model has been criticised because it lacks a foundation based on a behavioural model of the firm (Stoneman, 1983). The diffusion curves used by Mansfield, which describe the cumulative pattern of adopters of a new technology, are intended to model the behaviour of firms in the aggregate. It is, therefore, inevitable that they cannot explain why some firms adopt new technology or a new innovation earlier than others. By way of contrast, studies of adoption focus on what induces variations in the diffusion rate across firms, or what induces some firms to adopt more new technologies than others (Stoneman, 1986).

The second type of analysis uses the game theoretic approach, as developed by Dasgupta and Stiglitz (1980), Dasgupta (1986), Reinganum (1981a, 1981b), Fudenberg and Tirole (1985) and Tirole (1988). Game theory suggests that the profitability of the new technology combined with pressures from rivals to reduce costs will determine the timing of adoption.

Finally, inter-firm differences in technology adoption are explicitly modelled by employing Probit models (David, 1975, and Davies, 1979), and Bayesian learning models (Stoneman, 1981; Lindner, Fischer and Pardey, 1979; and Jensen, 1982 and 1983). In the Probit models an innovation is considered as a stimulus for a firm. Each firm is presumed to adopt an innovation only when the stimulus represented by an innovation itself exceeds a critical level, which varies across firms. In the empirical

[1] For excellent surveys, see Thirtle and Ruttan (1987), and Stoneman (1983, 1986, 1987).
[2] For a survey of the determinants of diffusion, especially the role of firm size and market structure, see Thirtle and Ruttan (1987).
[3] Although the literature on the diffusion of technological innovations sometimes treats diffusion and adoption in the same breath, there are differences between the two. Diffusion studies deal with the time pattern of the diffusion that may be expected following the adoption of a new technology, i.e., the cumulative pattern of adoption of a new technology. Adoption studies deal with the factors that determine the adoption of a technology by a firm at any point in time. See Thirtle and Ruttan (1987), Reinganum (1989), Metcalfe (1990), Davies (1979), Stoneman (1983), and Majumdar and Venkataraman (1993).
[4] See Mansfield (1961a, 1968).

studies based on these models the critical level is often taken to be a function of firm size and other firm characteristics.[5] In the Bayesian learning approach, firms are treated as being uncertain of the potential profitability of an innovation and are assumed to learn about the profitability either first hand or from an external source. In the empirical work associated with this theory, various characteristics such as firm size are assumed to be associated with a firm's capacity to learn.

Each of these approaches recognizes that technology usage varies across firms (Davies, 1979; Lane, 1991; Rogers, 1983; Reinganum, 1989). This suggests three research questions. First, what are the factors that determine whether a firm will adopt a given technology? Second, given that a new technology is available, why do some firms adopt a new technology or a new innovation earlier than others? Third, what is the process by which the new technology spreads, or diffuses, across the population? The first two questions are related to adoption, while the third one is related to diffusion.

This paper focuses on the second question[6]—the timing of adoption of advanced technologies.[7] Advanced technologies may generally be thought of as a cluster of technological innovations and thus share some basic technological properties (Dosi, 1982; Colombo and Mosconi, 1995). Their interdependence and complementarity are likely to greatly affect diffusion (Milgrom and Roberts, 1990). The paper analyzes the adoption of a cluster of technologies that are employed at various stages of the production process. These technologies pertain to design and engineering, fabrication and assembly, and inspection and communications. The design and engineering category consists of computer aided design (CAD) and /or computer aided engineering (CAE), CAD output used to control manufacturing machines (CAD/CAM), and digital representation of CAD output used in procurement activities. The fabrication and assembly category contains flexible manufacturing cells (FMC) or systems (FMS), numerically controlled and computer numerically controlled machines (NCM/CNCM), materials working lasers, pick and place robots, and other robots. The inspection and communications category consists of automated sensor-based equipment used for inspection/testing of incoming or in-process materials and final product, local area networks for technical data, local area networks for factory use, inter-company computer networks linking plant to

[5] A new technique is assumed to have higher fixed costs but lower variable costs than an old technique per unit of output. If positive returns to scale are assumed, then at a given time, the adoption of the innovation will be profitable only for firms above a given size. Naturally both the evolution of the technology and the growth of firms can change both the critical level and the number of potential adopters. The time path of diffusion will be determined by the existing distribution of firm size, by the rate of growth of individual firms and by the evolution of capital and labour costs.

[6] For a Canadian study addressing the first question, i.e., the determinants of technology adoption, see Baldwin and Diverty (1995).

[7] The term "advanced technology" is applied to a variety of manufacturing and communication technologies such as numerically controlled machine tools, robots, computer aided designs/computer aided manufacturing, flexible manufacturing systems, office automation (computer, work stations, terminals and peripherals, etc), telecommunications, among others. These technologies differ in their characteristics and are applied to various stages of manufacturing depending on their use (e.g., McFetridge (1992), Milgrom and Roberts (1990), Arcangeli, Dosi, and Moggi (1991), Edquist and Jacobsson (1988)).

subcontractors, suppliers, and/or customers, programmable controllers, and computers used for control on the factory floor.

Evidence shows that there has been a dramatic increase in the use of these technologies. For example, Edquist and Jacobson (1988) report that in Japan the share of numerically controlled machine tools (NCMT) in total machine tool investment increased from 28.3% in 1980 to 54.3% in 1984. Between 1980 and 1984 the share of NCMTs rose from 27.8% to 40.1% in the U.S., from 30.9% to 62.4% in the U.K., and from 28.6% to 59.4% in Sweden.[8] The average annual rate of increase in the number of robots installed in OECD countries was 44% during the period 1974-84. In 1984, in the engineering industry, the number of robots per 10,000 employees was 122.6 in Japan, followed by Sweden (70.1), Belgium (28.1), Italy (27.2), Germany (16.2), U.S.A. (14.8), France (14.7) and U.K. (8.5). According to Edquist and Jacobbson (1988) there were 6,600 CAD systems installed in the U.S. manufacturing industry in 1982. By 1985, the CAD systems in the U.S. manufacturing industry increased to 15,000.[9] Between 1989 and 1993 Canadian use of advanced technologies, in particular CAD, increased markedly (Baldwin and Sabourin, 1995).

The objective of this paper is to analyze the factors that affect the diffusion of these advanced technologies in the manufacturing sector. Particularly, the paper focuses on the determinants of the length of delay between a firm's becoming aware of the existence of a new technology and its adoption—the adoption lag.[10] It utilizes explanatory variables, suggested by both the decision and game theoretic approaches, as determinants of the observed variations in the adoption lag at the plant level. The analysis focuses on the roles of both characteristics of firms and technologies, and on the industrial environment in which firms operate.

This paper takes the following approach. First, it introduces ordered Probit and Logit models to capture the firm-level heterogeneity in the adoption lag. Second, it addresses adoption of a new technology at the micro (individual plant) level using a special survey. Third, it introduces several new variables relating to characteristics of both firms and technology that affect the adoption lag. In particular, it makes use of the benefits and costs relating to the implementation of advanced technologies that are perceived by plant managers. Fourth, it analyzes the determinants of the adoption lag for clusters of advanced technologies.

The paper is organized in the following way. Data sources and the heterogeneity in the rate of adoption of advanced technologies in Canadian manufacturing are described in section 2. Section 3 presents some evidence of firm-level variations in the adoption lag.

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[8] Between 1980 and 1985, the share of advanced automation (FMS,CAD,CAE,CAM, robots, etc.) as a percentage of investment increases from 0.6% to 4.7% in the U.S.A., from 1.6% to 6.7% in Japan, 0.2% to 2.6% in Europe, and 0.2 to 3.0% in Italy (Arcangeli, Dosi, Moggi, 1991).

[9] If, on average, there are four workstations per system, the number of workstations in 1982 was 26,400. Under the same assumption, the number of workstations had increased to 60,000 by 1985. The figure might not include PC-based units, which would result in an under-estimate of the stock of CAD.

[10] This definition of adoption lag is similar to that of Nabseth and Ray (1974).

Section 4 provides a conceptual framework of a firm's adoption decision and describes the factors that influence the adoption lag. The fifth section presents an empirical framework for modelling the inter-firm variations in the adoption lag—ordered Probit and Logit models. Section 6 presents variable definitions and measurements. Empirical results are discussed in section 7. The eighth section contains the conclusions.

2. Data Sources and Advanced Technology Use in Canadian Manufacturing

The data that are used here come from two sources—the 1993 Canadian Survey of Manufacturing Technology (SMT), which contains data on technology usage at the plant level, and the Canadian Census of Manufactures, which contains data on plant output and input, ownership, and diversification of a plant's parent firm. The responses to the SMT are linked to longitudinal panel data going back to 1973, taken from the Census of Manufactures.[11] This combined data file yields information not only on a plant's technology use, but also on its employment, shipments, wages, and value added in manufacturing. In addition, data on the plant's owning enterprise—nationality, employment and age—are generated from special files maintained by the Micro-Economic Analysis Division at Statistics Canada.

The 1993 Canadian SMT contains information on the use by establishments in the manufacturing sector of 22 separate advanced technologies. These technologies are grouped for the purpose of analysis here into several functional groups—design and engineering, fabrication and assembly, inspection and communications, automated material handling, manufacturing information systems, and integration and control. The survey, conducted by mail, was based on a sample of all establishments in the Canadian manufacturing sector. Of the 2,877 establishments in the sample, 2,351, or 88%, responded to the survey.[12] The survey provides information on the time between the firm's first knowledge of a technology and the firm's eventual adoption of the technology—the adoption lag. In addition, it contains extensive data on the characteristics of both technologies and firms sampled. In particular, both the benefits of and impediments to technology adoption are investigated.

The individual technologies included in the survey are listed in Table 1 by functional group. The functional groups differ in terms of the degree to which they are directly involved in the production and assembly process or whether they serve to monitor it via diagnostics and quality control. The technologies emanate from the current technological revolution that is related to the computer, or more correctly to microchip use. On the one hand, the relatively cheap processing power of microchips has spawned the development of a host of labour-saving technologies. These technologies have permitted the replacement of costly labour with efficient, reliable, computer-controlled machinery. For

[11] Of the 2,531 respondents, some 96% are linked into the panel from the Census of Manufactures.
[12] For more information on the survey, see Baldwin and Sabourin (1995).

example, robots provide an efficient and safe alternative to humans for repetitive jobs like spot welding or painting on the automobile assembly line. Automated guided vehicle systems replace delivery personnel.

As important as these labour-saving technologies might be, the new technological revolution has had equally important effects on the tasks that both production workers and managers perform. These technologies are all related to the information revolution. The dramatic impact of information technologies has been felt in many different parts of the production process. They have allowed management to receive, digest, and analyze unprecedented amounts of information. They have permitted designers to ponder problems that they did not have time to consider previously, and to shorten the design phase of projects. Inspection and communications, as well as integration and control technologies, facilitate the rapid transmission of orders to the assembly process, the delivery of parts to the assembler, and the assembly of specialized products by a worker who is instructed by a computer as to what parts are needed for the particular product ordered and the nature of the assembly required. Instead of replacing workers with robots, these technologies have enhanced human skills. In this environment, robots are relegated to repetitive tasks, while computer technologies aid workers to assemble custom-designed products with the aid of computer-transmitted requests.

It is worth emphasizing that even though the advanced technologies under examination in the Canadian manufacturing sector rest on the same scientific and technological knowledge base, the pace of their diffusion is not the same in different areas of production. In keeping with the importance of these advanced technologies for the information revolution, the inspection and communications functional group has the highest adoption rate (Table 1). Some 73% of shipments in 1993 come from establishments using labour-enhancing technologies from this group. The high adoption rate here is due mainly to the use of automatic control devices—programmable controllers and stand-alone computers used for control on the factory floor. The inspection and communications group is followed by design and engineering (62.5%) and manufacturing information systems (53.3%). Labour-saving technologies in fabrication, the traditional heart of the production process, are only fourth with 45.8%.[13] While the computer-based revolution is often described in terms of its effects on fabrication and assembly, its usage so far has been greatest in the area of the labour-enhancing technologies in inspection and communications as well as in design and engineering.

3. Technology Use and Adoption Lag

The data presented in the previous section indicate that the rate of adoption of advanced technologies differs according to their use in various stages of the firm's production process. Technology adoption enables establishments to increase both the quality and

[13] This type of gap in adoption in Canada is consistent with the findings of Colombo and Mosconi (1995). They report that at June 1989, the percentage of adopters in the Italian metal working industry was estimated at 18% for design and engineering equipment and 4.5% for manufacturing assembly systems.

quantity of outputs. Although the adoption of advanced technologies is crucial to a firm's ability to remain competitive, all potential adopters do not immediately implement new technologies.

A substantial proportion of firms take less than one year or more than three years to adopt advanced technologies (Table 2). However, the largest share is found in the 1-3 year time period. Except for automated material handling, there is a remarkable similarity across functional groups in the distribution of plants by time required for adoption.

While there are similarities in the average adoption lag across technologies, the adoption lag of individual plants varies substantially. For example, in the 1-3 year adoption lag category, the standard error ranges from 5.1 to 9.4 across technology groups. In addition, within each technology group, there is a wide variability across adoption lag categories. The standard errors range from 0.8 to 6.1 for design and engineering technologies; from 2.3 to 8.6 for fabrication and assembly and from 1.0 to 4.9 for inspection and communications technologies.

Table 1. ***Advanced Manufacturing Technologies by Functional Group***

Functional Group	Technology	Adoption Rate (% of Shipments)	
Design and Engineering		62.5	
	Computer-aided design and engineering (CAD/CAE)		60.8
	CAD output to control manufacturing machines (CAD/CAM)		21.2
	Digital representation of CAD output		17.8
Fabrication and Assembly		45.8	
	Flexible manufacturing cells/systems (FMC/FMS)		20.0
	Numerically Controlled (NC) and Computer Numerically Controlled (CNC) Machines		27.7
	Materials Working Lasers		7.5
	Pick & Place Robots		20.5
	Other Robots		14.2
Automated Material Handling Systems		16.1	
	Automated Storage/Retrieval Systems (AR/RS)		13.9
	Automated Guided Vehicle Systems (AGVS)		8.7
Inspection and Communications		72.9	
	Automatic Inspection Equipment - Inputs		31.6
	Automatic Inspection Equipment - Final Products		38.7
	Local Area Network for Technical Data		47.5
	Local Area Network for Factory Use		40.3
	Inter-Company Computer Network (ICCN)		33.9
	Programmable Controllers		57.5
	Computers used for control in factories		52.7
Manufacturing Information Systems		53.3	
	Materials Requirement Planning (MRP)		49.7
	Manufacturing Resource Planning (MRP II)		36.1
Integration and Control		41.7	
	Computer Integrated Manufacturing (CIM)		23.9
	Supervisory Control & Data Acquisition (SCADA)		35.3
	Artificial Intelligence/Expert Systems (AI)		9.0

There is, therefore, considerable heterogeneity in the timing of adoption of advanced technologies in Canadian manufacturing.

Table 2. ***Adoption Lag of Advanced Technology by Functional Group: Shipment Weighted***

Time Period	Design and Engineering	Fabrication and Assembly	Automated Material Handling	Inspection and Communications
	(percentage of shipments)			
Less than 1 year	25.1 (6.1)	24.1 (8.6)	15.5 (7.2)	15.0 (3.2)
1-3 years	45.1 (5.1)	45.0 (6.7)	72.3 (9.4)	45.5 (4.9)
3-5 years	20.1 (4.5)	17.3 (5.6)	5.1 (2.5)	18.9 (4.1)
More than 5 years	3.2 (0.8)	4.9 (2.3)	1.4 (1.1)	3.7 (1.0)
Non-response	6.5	8.7	5.7	16.9

Note: Figures in parentheses indicate corresponding standard errors.

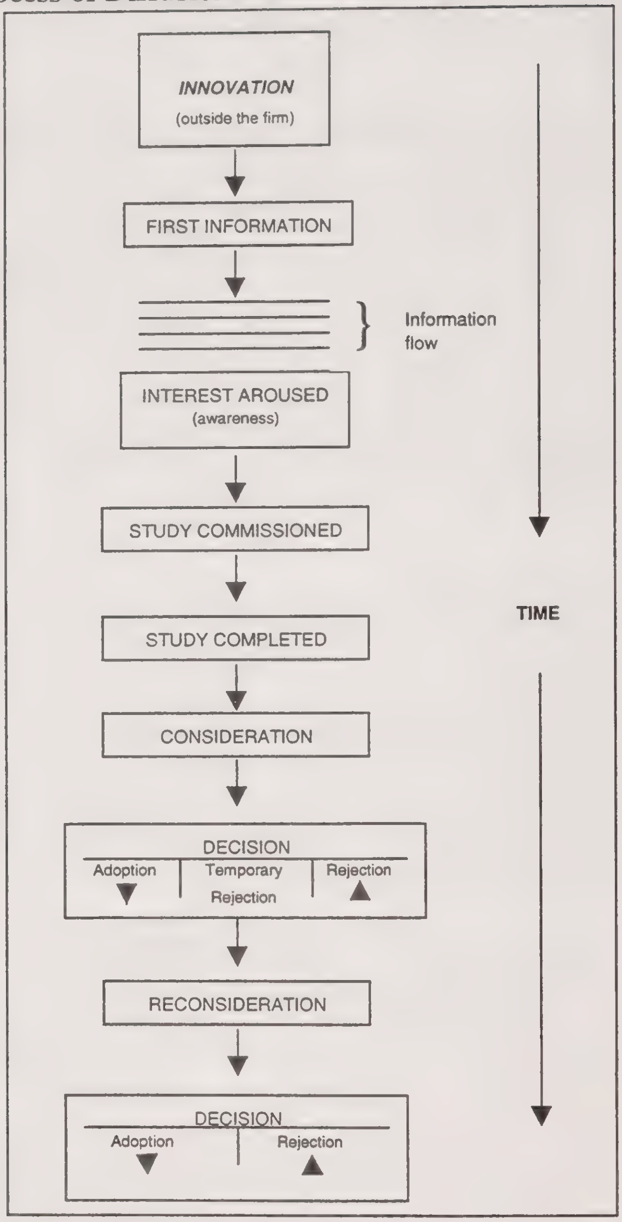
4. *A Conceptual Framework of Technology Adoption for a Firm*

A new technology passes through several stages of assessment before it is adopted. First, the benefits and costs of adopting the technology have to be assessed. Once the adoption decision is made, expertise has to be developed; staff has to be trained; the plant layout of the new equipment has to be planned; and workflows have to be reorganized. Finally, equipment embodying the new technology has to be ordered and delivered. These requirements determine the length of the adoption lag.

Adoption of an advanced technology takes place, as a rule, by installing the equipment embodying it. However, the point at which new equipment is installed is the last stage in a long process. In the first stage, information about the new technology enters the firm (Figure 1). Awareness of the advantages of the new technology is enhanced as more and more information flows into the firm via different sources—suppliers, trade shows, publications, affiliates or subsidiaries of a parent firm, consultants, various institutions such as university and government laboratories, or the firm's own production, design, engineering, and research and development groups.[14] Eventually the firm formally assesses the value of the technology. Finally, there is an additional lag between the decision to order the technology and its installation. The time between awareness and implementation—the adoption lag—varies across firms.

[14] On the relative importance of the various sources see Baldwin, Sabourin, and Rafiquzzaman (1996).

Figure 1. The Internal Process of Diffusion Within a Firm



Source: Nabseth and Ray (1974, p.7)

A Model of Adoption

Firms considering use of a new technology must decide whether and when to adopt. In general, this involves comparing the present value of expected benefits of innovation to the present value of the cost.

Let us consider a firm that is currently using existing technology, which will be referred to as the *incumbent technology*. [15] At some point in time, t = 0, the firm is faced with news of a major technological innovation. This innovation will be called the *current best technology*.

Denote x as the known benefits associated with the *incumbent technology* and y as the known benefits associated with the *current best technology*. The cost of adopting the current best technology is c, which includes purchase and installation costs as well as other disruption or switching costs. The incremental profitability of the current best technology is thus $(y - x) - c$. [16] Furthermore, assume that there will be no improvement in the current best technology until a future date t.

The firm's adoption decision to use the current best technology will depend on the net present value of this incremental profitability. The firm will adopt the technology by the future date t if the net present value of the incremental profit is positive. The size of this incremental net profit depends upon technology attributes; for example, the cluster of benefits and costs associated with the technology.

Nabseth and Ray (1974) argue many of the same factors that affect the decision to adopt the new technology also influence the length of the adoption lag. Although the main driving force behind the adoption and diffusion of a technology is increased profitability, i.e., positive net present value, there are other factors that may influence the adoption decision. The factors influencing the adoption of new techniques may be clustered into three categories: (1) the advantages of the technology as perceived by plant managers, (2) the characteristics of the potential adopters, i.e., size of firms,[17] and (3) the environment of the industry in which the firm operates. The first category includes the perceived benefits and costs of adopting the new technology. Since these perceptions may translate into different levels of net benefits for different types of firms, the second set, firm characteristics, is also included here. Finally the third set, industry characteristics, is included to test whether the competitive environment has an additional influence. The paper deals with each of these in turn.

4.1. Advantages of the New Technology

The advantages of adopting a new technology are determined by its profitability. The internal rate of return, in turn, depends upon the direct benefits, time savings, acquisition

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[15] On this, see Weiss (1994).

[16] If a non-negative pace of technological change is assumed then $(y - x) \geq 0$.

[17] See Zaltman, Duncan, and Holbeck (1973) for the sequence of decisions that organizations use in innovating and adopting new technologies. Heterogeneity posited here may involve any firm characteristic that is relevant to the adoption decision. For instance, David (1975) offers both theoretical and empirical arguments in favour of firm size. Other explanations, such as differential access to information and/or managerial willingness to take risks, are also common (e.g., Jensen (1982).

costs, assessment costs, compatibility with existing equipment, complexity, and divisibility for trial.[18]

Benefits

The new technique may save labour (skill); it may save capital through, for example, increased capital utilization and reduction in inventory (reduction in space requirements) or increasing yields because of fewer rejections. It may save raw materials and energy consumption. It may, of course, also save on one factor and simultaneously increase the use of another; e.g., it may be labour-saving and capital-using (i.e., require additional capital per unit of output). It may improve productivity[19] and may lead to higher quality of the products produced.

Since the adoption decision is affected by the benefits perceived to flow from the new technology and these vary by firm because firms differ in their capabilities, the timing of adoption of new technologies will not be uniform either across technologies or across firms. It is hypothesized that the larger the cluster of these benefits, the greater the incentive to earlier adoption.

Several benefits from technology adoption are identified by Canadian manufacturing firms—*increases in productivity, improvement in product quality, reduction in product rejection rate* (Baldwin, Sabourin, and Rafiquzzaman, 1996). Survey respondents generally list the benefits associated with improvements in productivity and product quality most frequently.[20]

Because different advanced technologies are used at various stages of the production process, their contributions to increases in benefits differ across technologies. Baldwin, Sabourin and Rafiquzzaman (1996) report that in the SMT survey, for any technology, at least 55%, 47%, and 18% of the shipments from technology users come from establishments that listed *improvement in productivity, improvement in product quality,* and *reductions in product rejection rate,* respectively. These responses differed across technology groups. In the case of *improvements in productivity*, about 70%, 76% and 55% of shipments originated in those establishments, listing an improvement in productivity, that used design and engineering, fabrication and assembly, and inspection and communications technologies, respectively. *Product quality improvement* ranks highest for fabrication and assembly, followed by inspection and communications and

[18] See Rogers (1983) for details.

[19] Adoption of advanced technologies saves costs, which improves productivity and increases profitability. In the broadest sense, one may classify the implementation of new technology as labour-, materials-, capital-, or energy-saving. These are expected physical effects and their economic effects depend on a variety of other factors. Of these, some are inherent in the technological characteristics of the innovation, such as new skill requirements, effects on managerial effort and managerial control, and the general need for learning.

[20] There are various routes by which productivity is improved; for example, reduction of labour requirements, reduction of material consumption, reduction in energy consumption, reduced capital investments. For details see Baldwin, Sabourin, and Rafiquzzaman (1996).

design and engineering. About 65%, 51% and 47% of shipments originated from those establishments using fabrication and assembly, inspection and communications and design and engineering technologies, respectively, that also listed product quality as a benefit.[21]

Costs

The implementation of new technology incurs various costs, such as outlays for equipment acquisition, expenditures on education and training, maintenance expenses, as well as the time and cost to develop software. To the extent that these costs are important dimensions of the firm's adoption decision, they should decrease the likelihood of early adoption.

Baldwin, Sabourin, and Rafiquzzaman (1996) report that *overall costs* is the most important factor that plant managers feel impeded them from acquiring advanced technologies.[22] Establishments affected by *overall costs* accounted for between 50% and 58% of shipments, regardless of the functional category group. There were, however, differences in emphasis across functional groups. *Overall costs* had about the same effects on design and engineering (50%) and inspection and communications (52%). Their effects were greater for fabrication and assembly (57%).[23]

Geographical Proximity of Suppliers

The decision to acquire a new technology depends on the availability, cost, quality, and a flow of information about its potential benefits. These vary substantially by supplier. In particular, it is hypothesized that it is more costly to evaluate technology coming from foreign producers of technology than from domestic producers because information is more costly to obtain and to process when it has to be transmitted over larger distances. Canadian plants adopt technologies made in Canada, U.S.A., Europe, and the Far East. It is hypothesized that the most distant sources will be associated with longer adoption lags.

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[21] For the relative importance of other benefits across technologies, see Baldwin, Sabourin and Rafiquzzaman (1996).

[22] *Overall costs* include *cost of technology acquisition, cost to develop software, cost of education and training, and increased maintenance expense.*

[23] For the relative importance of other costs associated with technology adoption, see Baldwin, Sabourin, and Rafiquzzaman (1996).

4.2. Characteristics of the Firm

Firm Characteristics Associated With Knowledge and Experience

The decision to adopt a new technology is hypothesized to depend not only on the intensity of the perceived costs and benefits associated with the technology, but also on the firm's economic and technological features that are associated with its capabilities to assess and to adopt technology—characteristics, such as investment intensity, size, nationality, age, the degree of diversification, and the intensity of technology use. While a firm's perception of benefits and costs will affect its adoption decision, its capabilities will determine the extent to which it can profitably implement new technologies. These capabilities are built up slowly over time. While not directly measurable, they are assumed here to be related to certain observable traits. More competent firms grow at the expense of others and become larger, last longer, are older, and prove able to absorb the most advanced technologies. This paper considers the following traits.

Investment Intensity

Investment intensity of a firm should a determinant of the adoption lag because it is correlated with underlying competencies. Firms differ substantially in terms of their ability to master advanced technologies. Firms that have invested heavily in advanced technologies are those with special competencies that are also likely to facilitate early adoption.

Technological Capability

Early adoption of a new technology by a firm depends on the firm's accumulated stock of knowledge. A firm's capabilities reflect its stock of knowledge and technical and managerial skills, all of which are enhanced by the use of previous technologies. These learning effects are expected to have a positive impact upon the probability of adoption and the adoption lag.

Incidence of Technology Use

A third trait that captures both accumulated knowledge and competency is the incidence of technology use in a plant. Plants that employ a wide range of advanced technologies have mastered a larger skill set than those using only one or two technologies. These plants are hypothesized to have shorter adoption lags.

Nationality of Ownership

Ownership of a plant by a multinational enterprise is cited as conducive both to higher net investment and to more rapid diffusion of technology (Cohen and Levin, 1989). Multinationals are vehicles through which hard-to-transfer scientific knowledge is moved from one country to another (Caves, 1982). This suggests foreign-owned firms may be the first to adopt new technologies. On the other hand, smaller Canadian-owned firms may have to show greater flexibility in order to survive. In this case, Canadian firms may prove to be the early adopters. Therefore, the relationship between ownership and adoption cannot be predicted *a priori*.

Firm Size

The theoretical and empirical literature on technology adoption suggests that firm size plays an important role in the decision to adopt new technologies (Davies,1979). In Davies' model, adoption occurs when a stimulus exceeds a threshold value for a firm. Variations in adoption occur because both stimuli and thresholds differ. Size is often assumed to be related to either stimuli or thresholds (Stoneman, 1986, Reinganum, 1989), since it acts as a proxy for such factors as risk aversion, participation in research and development activities, or economies of scale. In addition, it is generally argued that large firms can better diversify the risks of experimenting with the new technology than small firms.

Alternately, the Schumpeterian literature argues that large absolute firm size is a prerequisite to engaging in research and development activities and thus for the subsequent adoption of innovations. Other authors argue that relative not absolute firm size, e.g., market share, is an important determinant of innovation and technology adoption (Ravenscraft, 1983). Empirical studies yield mixed results on the relationship between technology adoption and firm size. Earlier studies by Mansfield (1968), Romeo (1975), and Nasbeth and Ray (1974) find that larger firms tend to adopt innovations sooner than do their smaller counterparts. Other statistical analyses yield mixed results. Oster's (1982) study of the diffusion of the basic oxygen furnace and continuous casting in the relatively concentrated U.S. steel industry suggests a negative effect of firm size on adoption probabilities. Levin, Levin and Meisel (1987) find negative effects of market concentration on the decisions of retail grocery stores to adopt optical scanner systems, but positive effects of market share; their study does not directly test the effect of firm size. In contrast, Hannan and McDowell (1984) find strong support of Schumpeterian models of innovation. They conclude that the hazard rate for adopting automatic teller machines rises with both absolute firm size and market concentration. More recently, Saloner and Shepard (1995) confirm the Hannan-McDowell results after including both network size and number of depositors of automated teller machines. In addition, Rose and Joskow (1990) find that large firms are significantly more likely to be among the early adopters of technological innovations in the electric utility industry, although the

relationship is non-linear. Given these empirical findings the impact of firm size on adoption lag is *a priori* uncertain.

Diversification

The level of diversification of a plant's parent enterprise is likely to decrease the adoption lag. If an enterprise operates in more than one industry, the knowledge gained in one plant from adoption of new technologies can be transferred to other plants.

Age

Another characteristic likely to be related to experience is the age of a firm. On the one hand, older firms generally will have accumulated knowledge stocks that allow them to assess new technologies better than younger firms. On the other hand, younger plants may be better able to adopt advanced technology than older plants whose capital stock may be outdated and less compatible with new technologies being adopted. The impact of age on adoption lag is therefore, difficult to predict *a priori*.

4.3. Environment of the Industry/Market Structure

Competitive pressures are presumed to affect both the rate of adoption of advanced technologies and the length of the adoption lag. The adoption of new technologies is crucial to a firm's ability to remain competitive (Clark, 1987). In a global economy, firms face constant pressures from competitors, both domestic and foreign, to reduce costs in order to remain competitive. Those firms that can reduce production costs by the timely adoption of technologies are able to offer lower prices and thus can maintain or increase their market share. Both the game theoretic and the empirical x-efficiency literature stress the importance of the competitive environment. Game theory suggests that competitive forces put pressures on firms for early adoption in order either to maintain market share or to pre-empt rivals.[24] Empirical work on the correlates of industrial efficiency consistently find that industries that are more open to trade are more efficient.[25]

Competition is often taken to be related to market structure. The impact of market structure upon the decision to adopt technologies has been extensively studied. However, both theoretical and empirical studies yield mixed results on the relationship between technology adoption and degree of competition. Mansfield (1968) and Romeo (1977) report evidence supporting the hypothesis that more competitive markets increase the rate of diffusion. On the other hand, Reinganum's (1981b) theoretical analysis demonstrates that, under certain conditions, increases in the number of firms in the market (i.e., more

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[24] In a leader-follower context, even if follower firms do not actually produce, their ability to produce at progressively lower cost levels exerts competitive pressure on the leader (Mookherjee and Ray, 1991).
[25] See Caves (1992).

competition) delays the adoption of a cost reducing, capital-embodied process innovation. The empirical evidence does not strongly support either position. In the case of automated teller machines, Hannan and McDowell (1987) find that the observed adoption by rivals increases the likelihood that potential adopters will themselves choose to adopt the innovation. On the other hand, Majumder and Venkataraman (1993) find that the adoption of a new technology, such as electronic switching, is not significantly related to the competitive pressures faced by a firm. Taymaz (1991) found in his study of the adoption of flexible automation in the U.S. engineering industry that high competition leads to higher rates of adoption, although the relationship was either statistically insignificant or weakly significant depending on the model chosen. Weiss (1994) finds statistically insignificant evidence that competition appears to reduce the tendency to suspend the adoption of "surface-mount technology". More recently, in the case of flexible manufacturing systems and CAD/CAM technologies, Colombo and Mosconi (1995) found a statistically insignificant relationship between competitive pressure and technology adoption.

5. *The Empirical Framework*

The SMT survey measures the average length of time between a firm's becoming aware of new technologies and its eventual implementation. The response categories used here are "less than one year", "1-3 years", "3-5 years", "5 or more years".[26] If the responses are coded as 0, 1, 2, or 3, they can be analyzed using ordered Probit and Logit models (Greene, 1997; McKelvey and Zavoina, 1975; Cramer, 1991; and Maddala, 1983). Which of these responses occurs in each observation is predicted by a linear function of a vector of explanatory variables of the form

$$y^* = \beta' \mathbf{x} + \varepsilon, \qquad (1)$$

where β is a vector of unknown parameters, $\mathbf{x}$ is a vector of explanatory variables, and ε is a vector of error terms. The linear function y^* is unobservable. What is observable is

$$\begin{aligned} y &= 0 \quad \text{if } y^* \leq 0, && (2) \\ &= 1 \quad \text{if } 0 < y^* \leq \mu_1, \\ &= 2 \quad \text{if } \mu_1 < y^* \leq \mu_2, \\ &= 3 \quad \text{if } \mu_2 \leq y^*, \end{aligned}$$

where μ's are unknown parameters to be estimated with β.

[26] Because of the very small number of responses in the category "more than 10 years", this category was collapsed into the "5-10 years" category.

If β is positive, the probability that $y = 0$ will decline for larger values of **x**. This implies that the probability that firms will adopt a technology in less than one year declines. In other words, the adoption lag increases.[27]

Models of most adoption studies involve dichotomous dependent variables—adoption versus non-adoption of technologies. The probabilities of the outcome of such variables, conditional on explanatory variables, are modelled using Probit and Logit analysis. In this analysis, although the measures of the adoption lag are qualitative, they are not dichotomous. When dependent variables are polytomous and ordered and are decomposed into dichotomous categories, valuable information inherent in the data set is lost. The simple Probit and Logit models cannot capture responses of such mutually exclusive multiple ordered categories. Ordered Logit and Probit models, however, do allow the prediction of the probabilities of any arbitrary number of mutually exclusive ordered responses.[28]

6. Definitions of Explanatory Variables

6.1. Advantages of the New Technology

Benefits

Respondents to the SMT survey identified several benefits from adopting advanced technologies. They are: *increased productivity, product quality improvement, reduced setup time, greater product flexibility, improved working conditions, and lower inventory.*[29] If a particular benefit is identified by a firm as being important, it is assigned a code 1; otherwise it is coded as 0. A composite index (BENEFIT) was constructed as the sum of the responses in these categories. The BENEFIT variable takes discrete values ranging from 0 to 6.

Costs

Respondents also identified the types of costs that hamper or delay advanced technology adoption. These include both general and specific costs, such as *technology acquisition costs, software development costs, education and training costs, and increased*

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[27] Under the assumption that ε is normally distributed, when β (positive) and μs are held constant, an increase in one of the X's shifts the distribution of the error term, ε to the right. As a result the probability of $y = 0$ declines and that of $y = 3$ increases. However, whether the probabilities of $y = 1$ and $y = 2$ increase or decrease can not be determined *a priori*. An examination of the impact of an increase of an explanatory variable on the probabilities of $y = 1$ and $y = 2$ requires the analysis of either the marginal effect or the quasi-elasticity of that variable.

[28] See Maddala (1983), and Greene (1997).

[29] There are other benefits that were also identified by the respondents. They were not included either because they were relatively less important or they were mutually correlated with the benefits included here.

maintenance expenses. The firm's responses to these categories were combined into a new variable, *overall cost* (COST) [30], defined to take on a value of 1 if the firm found *any* of the cost categories to hamper its adoption of new technologies, and a value of 0 otherwise.

Geographical Proximity of Suppliers

The geographical proximity variables are generated from information on the principal regional sources of respondents' advanced technologies. When the sources are Canada, United States, Europe, the Pacific Rim countries, and other areas, respectively, the geographic proximity variables are GEO-CAN, GEO-US, GEO-EURO, GEO-PRIM, and GEO-OTH. They are binary variables that take on the value of 1 when the principal source is one of these regions, or 0 if otherwise.

6.2. Firm Characteristics

Age: Two dummy variables are used to capture age effects—one for plants born during the 1970s (AGE1), and a second for plants born in the 1980s (AGE2).

Investment Intensity

This is measured by the share of total investment that is made in technologically advanced equipment and software (INVESTMENT). This variable is defined at the functional group level—e.g., design and engineering, fabrication and assembly.

Firm Size

In order to capture size effects, both absolute and relative measures of firm size are used. Plant size represents the absolute size effects and is measured by the number of production and non-production workers employed by the plant in 1993. Three binary size-class variables are specified—plants with less than 100 employees (PLANTSIZE1), those with between 100 and 500 employees (PLANTSIZE2), and those with more than 500 employees (PLANTSIZE3). In order to capture the relative size effects, the market share of the firm as of 1993 (SHARE-93) is employed.

Diversification

The level of diversification of a firm's parent enterprise is measured as the number of industries at the 4-digit level in which the establishment's parent has production facilities.

[30] A principal component analysis was done to identify the importance of all types of costs. *Overall costs* explained the largest variation. In addition, all other specific costs were correlated with *overall cost*.

Four dummy variables are used. They are enterprises with plants in one (DIVERSE1), two (DIVERSE2), three (DIVERSE3), and four or more (DIVERSE4) 4-digit industries.

Nationality of Ownership

To capture the effect of nationality, a binary variable (CANADIAN-OWNER) is included that equals 1 if a manufacturing plant is Canadian-controlled, and 0 otherwise.

Technological Capability

Technological capability of a firm is measured here by a self-evaluation of the firm's technology relative to its most significant competitors. The measure captures the firm's relative technological capability gained from cumulative learning experience. Since competitors faced by Canadian firms are located both within Canada and abroad, the firm's technological capability is measured relative to both domestic and foreign competitors.

Technological capabilities were evaluated relative to both their domestic and foreign competitors on a five-point scale: 1 (much less advanced), 2 (less advanced), 3 (about the same), 4 (more advanced), and 5 (much more advanced). CAPABILITY-D takes on a value 1 if the firm's current technology is as good as or better than its domestic competitors, and 0 otherwise.[31] CAPABILITY-F takes on a value 1 if the firm's current technology is as good as or better than its foreign competitors, and 0 otherwise.

Incidence of Technology Use

The intensity of adoption of different technologies is measured by a variable that represents the breadth of technology use within a particular stage of production. Firms indicated whether they were currently using any of 22 advanced technologies (Table 1). These technologies were divided into six groups according to their use in different stages of production. Three of the 22 technologies belong to the design and engineering group, five to the fabrication and assembly group, and seven to the inspection and communications group. Intensity of adoption (ADOPT-INTENSITY) captures the extent to which a firm is using technologies within a group. If a plant uses an advanced technology, the binary variable takes on a value 1, and 0 otherwise. As a result, the ADOPT-INTENSITY variable assumes discrete values ranging from 0 to 3, 0 to 5, and 0 to 7 in the design and engineering, fabrication and assembly, and inspection and communications groups, respectively.

[31] A firm's current technology is as good as or better than its competitors if its score was either 3 or 4 or 5.

6.3. Environment of the Industry/Market Structure

Finally, competitive pressure on a firm is measured by the number of firms directly competing with it in the Canadian market. Firms indicated whether they faced 1-5 competitors, 6-20 competitors, over 20 competitors, or no competition. In order to control the effects of competitive pressure, four dummy variables are used. These are enterprises facing 1-5 competitors (N-COMP1), 6-20 competitors (N-COMP2), over 20 competitors (N-COMP3), and no competitors (N-COMP4).

7. Results

The parameter estimates of the ordered Probit model (1) for each of the three advanced technology groups are presented in Table 3.[32] When performing the regression, the omitted categories are: the plants born before 1980, those that were foreign-owned, had 0 competitors, were diversified across four or more 4-digit SIC industries, and derived their technologies from "other" geographic areas. As the Chi-square statistics show, the null hypothesis that the explanatory variables are jointly insignificant is rejected for each technology group.

The BENEFIT coefficients are always significant and the COST coefficients are significant for two of the three functional groups. This confirms that both costs and benefits are significant determinants of the adoption lag. The positive coefficient on COST demonstrates that an increase in cost decreases the probability of early adoption and hence increases the adoption lag. The negative coefficient on BENEFIT indicates the opposite effect. Previous studies (Lane, 1991; Rose and Joskow, 1990) have used proxies, such as firm size, to represent the benefits that are derived from technology acquisition. This study finds that direct evaluations by the industry participants act as strong explanations for the investment decision.

The coefficients on the geographic proximity variables broadly support the negative impact of distance. The coefficients attached to the GEO-CAN variable are negative for all technologies and significant for inspection and communications technologies. This indicates that, when Canada is a source of advanced technologies, the probability of early adoption increases. The GEO-US coefficient is positive and significant in the case of fabrication and assembly technologies. The probability of early adoption of fabrication and assembly technologies declines when the U.S. is the source of technologies. Firms have a tendency to adopt all types of advanced technologies late if the source is Pacific-Rim countries as indicated by a positive coefficient on the GEO-PRIM variable. This is significant in the case of inspection and communications technologies.

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[32] Since there were no qualitative differences in the parameter estimates between ordered Probit and ordered Logit models, the results of the ordered Probit model are presented here.

Generally, the coefficient on plant size is negative but not statistically significant.[33] The negative coefficient on PLANTSIZE2 indicates that the probability of early adoption initially increases with firm size. But the positive effect of size is generally reduced for firms of over 500 employees.

Turning to the relative firm-size variable, market share (SHARE-93) displays a negative, but insignificant coefficient, providing weak evidence that as relative firm size increases, the adoption lag declines.

As expected, the two variables (CAPABILITY-D and CAPABILITY-F) that capture technological capability everywhere play a very significant role in determining the adoption lag. The coefficients of both CAPABILITY-D and CAPABILITY-F are negative and generally significant across all technologies. An increase in a firm's technological capability relative to both its domestic and foreign competitors speeds up adoption and hence reduces the adoption lag.

A firm's investment intensity (INVESTMENT) has a significant negative effect on the length of the adoption lag for inspection and communications and fabrication and assembly technologies. In contrast, it does not have a tendency to reduce the adoption lag for design and engineering technologies.

The negative and significant coefficient on AGE2 indicates that plants born in the 1980s have a shorter adoption lag than those born in the 1970s.

Ownership of a plant by a multinational enterprise is sometimes cited as conducive both to higher net investment and to more rapid diffusion of technology (Cohen and Levin, 1989). The results do not confirm this hypothesis. The negative and highly significant coefficient of CANADIAN-OWNER for both inspection and communications and design and engineering technologies shows that plants under Canadian control have a tendency to adopt these technologies earlier than their foreign counterparts. A similar result occurs for fabrication and assembly technologies, although the effect is not statistically significant.

Diversification significantly increases the likelihood of early adoption of both inspection and communications and design and engineering technologies since the coefficient for enterprises in one industry is significantly smaller than the coefficient for enterprises having plants in four or more four-digit industries. A completely different picture emerges in the case of fabrication and assembly technologies. The positive coefficient of all diversification variables suggests that the diversification effect is not important here.

The incidence of technology use (ADOPT-INTENSITY) shortens the adoption lag although the effects are not statistically significant.

[33] Omission of the benefit, cost, and capability variables does not make the size variables significant.

Finally, the level of competition in the adopting firm's industry increases the probability of delaying the adoption decision process across all technologies. The coefficients of N-COMP1, N-COMP2, and N-COMP3 are positive. They are highly significant for inspection and communications and design and engineering technologies; insignificant for fabrication and assembly technologies. While the coefficients on these three variables are positive, they are generally not significantly different from one another. This means that having some competition matters, but there is no relationship between the adoption lag and the number of competitors where this number has a positive value.

Further Results: Marginal Effects

The parameter estimates of the ordered Probit model (Table 3) only provide the effects of changes in explanatory variables on two extreme probabilities. They provide the direction of the effects of explanatory variables on the probability of adoption in less than one year and the probability of adoption in more than five years. They, however, cannot provide the direction of the effects of changes of explanatory variables on the probability of adoption within 1-3 years and 3-5 years. In order to estimate the direction and magnitude of these changes, marginal effects analysis or the analysis of quasi-elasticities is required (Cramer, 1991).

Tables 4, 5, and 6 translate the parameter estimates from equation (1) into percentage changes in the probability of adopting advanced technologies for unit changes in each of the explanatory variables. They are quasi-elasticities.[34] They measure the magnitude and direction of the changes in the adoption lag with respect to changes in each explanatory variable.

An examination of the quasi-elasticities confirms the previous findings. For example, the COST quasi-elasticity is positive when the adoption lag is less than one year, and negative when it is more than 5 years (Tables 4-6). This indicates the probability that firms will adopt advanced technology in less than one year declines, while the probability that they will adopt in more than 5 years increases. The COST quasi-elasticity also provides an estimate of the magnitude of the changes. For example, in the case of inspection and communications technologies, a 10% increase in costs decreases the probability of early adoption by about 0.57% and increases the probability of late adoption by about 0.21% (col. 2 and col. 5, Table 4). Similar qualitative cost effects are observed for design and engineering (col. 2 and col. 5, Table 5) and fabrication and assembly (col. 2 and col. 5, Table 6) technologies.

In contrast, the BENEFIT quasi-elasticities show opposite effects across all technologies. For example, in the case of inspection and communications technologies, a 10% increase in benefits increases the probability of early adoption by about 1.27% and decreases the probability of late adoption by about 0.47% (col. 2 and col. 5, Table 4). In the case of

[34] Note that quasi-elasticities (Tables 4-6) with respect to each explanatory variable sum to zero. This is because probabilities sum to one, their derivatives sum to zero, and so do the quasi-elasticities.

design and engineering (col. 2 and col. 5, Table 5) and fabrication and assembly (col. 2 and col. 5, Table 6) technologies, similar effects of benefits are observed. In addition, a comparison of BENEFIT and COST quasi-elasticities also confirms that the adoption lag is more sensitive to changes in benefits than to changes in costs.[35]

Quasi-elasticities also provide the percentage change in the probability of adoption for the periods 1 to 3 years and 3 to 5 years for unit changes in each of the explanatory variables (Tables 4-6). For example, the COST quasi-elasticity for the 1-to-3-year and the 3-to-5-year adoption lags is negative for all technologies. The BENEFIT quasi-elasticity is positive for the same adoption lags. This indicates that higher costs increase the probability of adoption at later dates. An increase in benefits does the opposite. In addition, for BENEFIT and COST variables, the magnitude of the quasi-elasticity in column 4 is larger than the magnitude of the quasi-elasticity in columns 3 and 5. This suggests that the effects of the changes in costs and benefits are concentrated in the 3-to-5-year lag category.

The magnitude and direction of the changes in the adoption lag due to changes in other explanatory variables may be observed in Tables 4, 5 and 6. Elasticity values indicate that the effects of the changes in each explanatory variable are generally concentrated in the 3 to 5 year lag category.

8. Discussion and Conclusions

Previous studies of technology adoption and diffusion have had to rely upon rough proxies of firms' competencies, such as firm size. This study uses a richer set of variables that more directly measure both technology and firm attributes. The results show that technology attributes predominantly affect the adoption lag across all technology groups. Most of the variables associated with firm characteristics preserve their signs, when the former set of variables is added to the regression, although some of them have an insignificant effect on the adoption lag. Competitive pressure in the adopting firms' industry as measured by number of firms in the industry—an element of market structure—does not have a monotonic effect.

The principal result of interest concerns the effects of costs and benefits on adoption. Firms vary considerably in terms of their abilities to achieve the benefits associated with technology adoption. Higher benefits are associated with earlier adoption. On the other side of the coin, when costs are perceived as an impediment, the adoption lag is longer. The length of the adoption lag is more sensitive to the effect of benefits than costs. The results also show that geographic proximity is an important factor relating to the speed of adoption. If advanced technologies are available at home, firms tend to adopt them early.

[35] The BENEFIT quasi-elasticity is larger than the COST quasi-elasticity across all technologies (col. 2 and col. 5, Tables 4-6).

If they are available in foreign countries, especially in Pacific Rim countries, firms tend to adopt them late.

The paper also tested the impact of several new variables of competency relating to technological capabilities of firms on the adoption lag. The variables are technological competitiveness and the investment capability of a firm. Both variables shorten the adoption lag. Firms with better technological and investment capabilities have a tendency to adopt technologies earlier.

The empirical results show that ownership and age of the plant are two firm characteristics that significantly affect the adoption lag. Both support the hypotheses concerning the adoption lag. Newer plants tend to adopt all technologies earlier than older plants.

Contrary to expectations, our data show that Canadian-owned plants adopt technologies earlier than their foreign counterparts. In this context, our data show no evidence that multinational firms are more conducive to rapid diffusion of technology as suggested by Cohen and Levin (1989) and Caves (1982).

With respect to firm size, it should be noted that while both the theoretical and empirical literature yield mixed predictions about the effect of firm size on technology adoption, our data find a little association between firm size and technology adoption. The evidence only weakly supports the Schumpeterian view: larger absolute firm size means a firm is more likely to adopt all technologies earlier than smaller firms. But the absolute size effect generally vanishes after a threshold level of more than 500 employees. The effect of relative firm size is similar to that of absolute firm size. Our results show relative size effects reduce the length of the adoption lag—but the effect is statistically insignificant.

Finally, the results shed light on the effects of competitive pressure on adoption lag. We find that firms with no competitors adopt earlier, but there is little difference in the length of lag for all positive values of number of competitors.

Table 3. ***Determinants of Adoption Lag: Ordered Probit Model***

Variable	Inspection and Communications (1)		Design and Engineering (2)		Fabrication and Assembly (3)	
	Parameter Estimate	S.E.[a]	Parameter Estimate	S.E.[a]	Parameter Estimate	S.E.[a]
Intercept	1.4545 ***	0.4435	1.2589 **	0.5116	1.1154 ***	0.3879
COST	0.2118	0.1327	0.2361 **	0.1136	0.2401 **	0.1191
BENEFIT	-0.3271 **	0.1359	-0.3410 ***	0.1259	-0.0648 *	0.0367
GEO-CAN	-0.2749 **	0.1422	-0.0887	0.1207	-0.1369	0.1191
GEO-US	0.1138	0.1418	-0.1354	0.1226	0.2030 *	0.1236
GEO-EURO	-0.0020	0.2988	-0.0638	0.1926	-0.0339	0.1687
GEO-PRIM	0.4752 *	0.2643	0.0026	0.3434	0.1431	0.2019
CAPABILITY-D	-0.5208 ***	0.1613	-0.3857 ***	0.1406	-0.1094	0.1447
CAPABILITY-F	-0.2751 **	0.1423	-0.1436	0.1150	-0.2924 **	0.1227
INVESTMENT	-0.0045 **	0.0020	0.0004	0.0016	-0.0045 ***	0.0018
AGE2	-0.2518 *	0.1418	-0.2101 *	0.1237	-0.2910 **	0.1268
PLANTSIZE2	-0.1019	0.1447	-0.1227	0.1240	-0.2139	0.1335
PLANTSIZE3	0.1014	0.2509	-0.2000	0.2231	-0.0757	0.2231
DIVERSE1	-0.4152 **	0.1680	-0.3049 **	0.1543	0.1107	0.1533
DIVERSE2	-0.2306	0.2158	-0.2443	0.1984	0.0469	0.2105
DIVERSE3	0.1940	0.2867	-0.0012	0.2446	0.0135	0.2582
CANADIAN-OWNER	-0.4643 ***	0.1445	-0.3581 ***	0.1282	-0.1358	0.1455
N-COMP1	0.9807 **	0.4003	0.9236 *	0.4787	0.3311	0.3634
N-COMP2	0.8608 **	0.3927	0.7702 *	0.4640	0.5491	0.3540
N-COMP3	1.0844 ***	0.3895	0.8175 *	0.4626	0.5489	0.3502
SHARE-93	-0.2079	0.4412	-0.1008	0.4142	-0.2354	0.3946
ADOPT-INTENSITY	-0.0219	0.0381	-0.0800	0.0689	-0.0116	0.0671
μ_1	1.5746 ***	0.0967	1.5687 ***	0.0824	1.5655 ***	0.0835
μ_2	2.3907 ***	0.1399	2.3064 ***	0.1173	2.3485 ***	0.1150
Log likelihood	-406.32		-524.11		-491.86	
Restricted Log Likelihood	-445.21		-553.39		-513.09	
Chi-square	77.77 ***		58.55 ***		42.45 ***	
N[b]	378		481		441	

[a] Standard error. [b] Number of observations. *** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level.

Table 4. ***Quasi-Elasticities of Adoption Lag with Respect to Regressor Variables: Inspection and Communications Technology***

Variable	Adoption lag:Y = 0 (less than 1 year)	Adoption lag:Y = 1 (between 1 to 3 years)	Adoption lag:Y = 2 (between 3 to 5 years)	Adoption lag:Y = 3 (more than 5 years)
COST	0.0567	-0.0010	-0.0349	-0.0208
BENEFIT	-0.1274	0.0021	0.0784	0.0469
GEO-CAN	-0.1158	0.0020	0.0714	0.0424
GEO-US	0.0430	-0.0008	-0.0265	-0.0158
GEO-EURO	-0.0001	0.0000	0.0001	0.0000
GEO-PRIM	0.0140	-0.0002	-0.0086	-0.0052
CAPABILITY-D	-0.3065	0.0052	0.1887	0.1127
CAPABILITY-F	-0.1278	0.0022	0.0787	0.0469
INVESTMENT	-0.1023	0.0000	0.0630	0.0393
AGE2	-0.0629	0.0011	0.0388	0.0230
PLANTSIZE2	-0.0339	0.0006	0.0209	0.0125
PLANTSIZE3	0.0078	-0.0001	-0.0048	-0.0029
DIVERSE1	-0.1593	0.0027	0.0981	0.0585
DIVERSE2	-0.0200	0.0004	0.0123	0.0073
DIVERSE3	0.0103	-0.0002	-0.0064	-0.0038
CANADIAN-OWNER	-0.2303	0.0039	0.1419	0.0846
N-COMP1	0.1448	-0.0025	-0.0891	-0.0532
N-COMP2	0.2424	-0.0041	-0.1492	-0.0891
N-COMP3	0.3266	-0.0056	-0.2012	-0.1198
SHARE-93	-0.0165	0.0003	0.0101	0.0060
ADOPT-INTENSITY	-0.0448	0.0007	0.0276	0.0166

Table 5. *Quasi-Elasticities of Adoption Lag with Respect to Regressor Variables: Design and Engineering Technology*

Variable	Adoption lag:Y = 0 (less than 1 year)	Adoption lag:Y = 1 (between 1 to 3 years)	Adoption lag:Y = 2 (between 3 to 5 years)	Adoption lag:Y = 3 (more than 5 years)
COST	0.0729	-0.0061	-0.0395	-0.0274
BENEFIT	-0.1760	0.0145	0.0952	0.0663
GEO-CAN	-0.0364	0.0030	0.0198	0.0137
GEO-US	-0.0539	0.0044	0.0291	0.0203
GEO-EURO	-0.0032	0.0003	0.0017	0.0012
GEO-PRIM	0.0000	0.0000	0.0000	0.0000
CAPABILITY-D	-0.2457	0.0204	0.1330	0.0923
CAPABILITY-F	-0.0648	0.0053	0.0351	0.0243
INVESTMENT	0.0096	0.0000	-0.0096	0.0000
AGE2	-0.0584	0.0048	0.0317	0.0219
PLANTSIZE2	-0.0371	0.0031	0.0201	0.0139
PLANTSIZE3	-0.0149	0.0012	0.0081	0.0056
DIVERSE1	-0.1306	0.0108	0.0708	0.0491
DIVERSE2	-0.0229	0.0019	0.0124	0.0086
DIVERSE3	-0.0001	0.0000	0.0000	0.0000
CANADIAN-OWNER	-0.1981	0.0165	0.1073	0.0743
N-COMP1	0.1494	-0.0124	-0.0808	-0.0562
N-COMP2	0.2117	-0.0175	-0.1145	-0.0797
N-COMP3	0.2684	-0.0222	-0.1453	-0.1009
SHARE-93	-0.0060	0.0005	0.0033	0.0023
ADOPT-INTENSITY	-0.0776	0.0063	0.0418	0.0295

Table 6. ***Quasi-Elasticities of Adoption Lag with Respect to Regressor Variables: Fabrication and Assembly Technology***

Variable	Adoption lag: Y = 0 (less than 1 year)	Adoption lag: Y = 1 (between 1 to 3 years)	Adoption lag: Y = 2 (between 3 to 5 years)	Adoption lag: Y = 3 (more than 5 years)
COST	0.0811	0.0112	-0.0530	-0.0392
BENEFIT	-0.1292	-0.0174	0.0842	0.0624
GEO-CAN	-0.0401	-0.0055	0.0262	0.0194
GEO-US	0.0672	0.0093	-0.0439	-0.0326
GEO-EURO	-0.0048	-0.0007	0.0031	0.0023
GEO-PRIM	0.0092	0.0013	-0.0060	-0.0045
CAPABILITY-D	-0.0641	-0.0088	0.0419	0.0310
CAPABILITY-F	-0.1160	-0.0161	0.0760	0.0561
INVESTMENT	-0.1592	-0.0265	0.1061	0.0796
AGE2	-0.0730	-0.0101	0.0477	0.0354
PLANTSIZE2	-0.0585	-0.0081	0.0382	0.0283
PLANTSIZE3	-0.0040	-0.0006	0.0026	0.0020
DIVERSE1	0.0445	0.0062	-0.0291	-0.0215
DIVERSE2	0.0044	0.0006	-0.0029	-0.0021
DIVERSE3	0.0006	0.0001	-0.0004	-0.0003
CANADIAN-OWNER	-0.0675	-0.0092	0.0442	0.0326
N-COMP1	0.0468	0.0064	-0.0306	-0.0226
N-COMP2	0.1474	0.0203	-0.0964	-0.0713
N-COMP3	0.1579	0.0217	-0.1033	-0.0763
SHARE-93	-0.0064	-0.0009	0.0042	0.0031
ADOPT-INTENSITY	-0.0075	-0.0009	0.0049	0.0035

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